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FLOW METER CALIBRATIONS FOR THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS RESEARCH COMMITTEE ON FLUID METERS

A Research and Development Report
NBTL Project I-295
31 October 1962

by
C. GREGORY

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## ABSTRACT

Six nozzles and two orifices were calibrated in pairs, one of a pair with water (240 F, 2200 psia) at the inlet and the other with steam (1050 F, 2000 psia) at the outlet of an operating boiler. Pipe Reynolds numbers averaged 600,000 for the water and 4,000,000 for the steam. Coefficients were generally in agreement with ASME.

Type 430 stainless steel proved a better material of construction for the steam conditions than 2-1/4% chrome-molybdenum steel. The latter material showed considerable rusting and pitting after less than 10 hours of operation.

## SUMMARY PAGE

### The Problem

To obtain weighed water calibrations of nozzles and orifices at pressures and temperatures above those now verified.

### Findings

Coefficients for an 0.58 beta steam nozzle were found to be about one percent higher and for an 0.73 beta nozzle about 1.5 percent higher, than coefficients from current ASME publications. Coefficients for an 0.65 beta steam orifice were also higher by about one percent. Coefficients for two water nozzles were in good agreement, within plus and minus one percent, of the ASME. Those for a water orifice were about 1/2 percent lower.

## ADMINISTRATION INFORMATION

References :

(a) ASME ltr to Director NBTL of 28 Oct 1957

(b) NBTL ltr Code 760/A19 to ASME of 7 Nov 1957

(c) ASME ltr to Director NBTL of 24 Jul 1959

By reference (a), the Research Committee on Fluid Meters of the ASME requested the Naval Boiler and Turbine Laboratory to provide facilities for measuring high pressure steam flow. The Laboratory agreed to undertake the work as described in reference (b). Preliminary funds and authority to proceed with the work were contained in reference (c). Subsequently, funds in the amount of $39,000.00 were forwarded to NBTL by the ASME to cover total cost of the project.

INTRODUCTION

In determining steam generator efficiency, either the feed water inflow or the steam outflow is measured. High pressure, high temperature water or steam flow must be measured with maximum accuracy and when both are measured simultaneously, the two quantities do not always agree, thus raising a question as to which is correct. There is also uncertainty as to values of physical properties of steam and water higher than the verified limits.

Subcommittee number seven of the ASME Research Committee on Fluid Meters requested the Naval Boiler and Turbine Laboratory to conduct tests on nozzles and orifices operating with high pressure and high temperature steam and water.

DESCRIPTION

The Laboratory's 1050 F, 2000 psia boiler was used for the tests. The water nozzles and orifice were installed in the feed water line upstream of the economizer inlet of the boiler. The steam nozzles and orifice were installed in the superheater outlet line of the boiler. Flow straighteners were installed upstream of both test sections.

The Bailey Meter Company supplied the flow sections, flow straighteners, nozzles and one orifice to be used in the test operation. Six long radius nozzles and two orifice plates were calibrated. Primary element information is given in Table 1. The orifice made by NBTL, which was of the same construction as the one made by Bailey Meter Company, is shown in Figure 1. Bailey's original steam orifice was made of chrome-molybdenum steel. Subsequent testing with nozzles showed that this material was unsatisfactory

for the steam service and as a consequence NBTL made an additional orifice of type 430 stainless steel.

The test sections are described in Bailey Meter Company drawings D394430A and D394431A, showing respectively the feed water and the steam flow pipe assemblies.

TEST ARRANGEMENT

The system flow diagram is shown in Figure 2. Two weighing systems were used to weigh the water. Thus while one system was supplying the weighed water to the feed water heater, the other was being filled. The feed water heater used low pressure superheated steam to heat the water from ambient temperature to approximately 240 F. The amount of steam introduced was determined by heat [illegible] to the weighed flow. Feed water pumps then boosted the pressure to that required by the boiler. The water passed through the water [illegible] into the boiler. The superheated steam leaving the boiler passed through the steam flow section, thence to a condenser.

Table 1

Primary Element Information

| Run | Fluid | Primary Element | | | | |
|---|---|---|---|---|---|---|
| | | Type | Serial No. | Diameter, In. | Beta | Material |
| 1-4 | Water | Nozzle | 129857 | 1.3734 | 0.3887 | 304 stainless steel |
| | Steam | Nozzle | 129861 | 2.1862 | 0.5819 | 2¼% chrome moly steel |
| 5-8 | Water | Nozzle | 129858 | 1.7190 | 0.4865 | 304 stainless steel |
| | Steam | Nozzle | 129862 | 2.7350 | 0.7280 | 2¼% chrome moly steel |
| 10-13 | Water | Nozzle | 129857 | 1.3734 | 0.3887 | 304 stainless steel |
| | Steam | Nozzle | 132243 | 2.1867 | 0.5820 | 430 stainless steel |
| 14-17 | Water | Orifice | 129859 | 1.4380 | 0.4070 | 304 stainless steel |
| | Steam | Orifice | NBTL | 2.4425 | 0.6501 | 430 stainless steel |
| 19-26 | Water | Nozzle | 129858 | [illegible] | [illegible] | [illegible] steel |
| 19-21 | Steam | Nozzle | 133184 | 2.7335 | 0.7276 | 430 stainless steel |
| 22 | Water | Nozzle | 133184 | 2.7335 | 0.7276 | 430 stainless steel |
| 23-26 | Steam | Nozzle | 133184 | 2.7335 | 0.7276 | 430 [illegible] steel |

INSTRUMENTATION

All instrument readings were synchronized by means of electrical time signals at three minute intervals.

Temperature

All temperatures were measured by means of calibrated iron-constantan thermocouples. Cold junctions were maintained at 32 F. Temperatures or millivolts were recorded or indicated on calibrated potentiometers.

Pressure

Water and steam pressures were indicated on 12 inch laboratory type gages. In addition, the steam pressure at the primary element was measured with a dead weight gage. All instruments were calibrated before test.

Differential Pressure

Each primary element had two separate sets of pressure taps. Where possible, more than one manometer was used for each differential pressure measurement. Steam differentials were indicated on two 120 inch, "U" tube manometers. An Exactel manometer with digital readout to 0.002 inches was installed on the water flow section. In addition, an inclined manometer and two upright well type manometers were used when necessary. The indicating fluid was mercury under water in all manometers.

DISCUSSION

Data taking was not started until boiler variables had become reasonably stable. Data were recorded on feed water heater level and boiler drum level. Generally, run time was selected so that these levels

were the same at the end of the run as at the start. Every effort was made to hold other variables as constant as possible.

Since it was not possible to completely eliminate leakage, the actual leakage rates were determined at least twice during each run by collecting the water and weighing. Only in this way could the quantities of fluid entering each measuring section be accurately determined. For this reason the actual flow rates of water and steam will be slightly different.

The first steam nozzles were 2½% chrome molybdenum steel. After about 10 hours of operation, examination of the nozzle revealed rusting and pitting. As a consequence, two new nozzles were made of type 430 stainless steel. These latter nozzles did not rust or pit and apparently are better suited for operation at temperatures around 1050 F.

The water orifice was supplied by the Bailey Meter [illegible] steam orifice by the Naval Boiler and Turbine Laboratory. The latter orifice was made of type 430 stainless steel. The pressure taps in both flow sections conformed to ASME requirements for vena contracta taps for square-edged orifices on the downstream, but not the upstream section.

The water nozzle calibrations are shown in Figure 3. Excellent agreement with ASME coefficients was obtained.

Figure 4 shows the results of the steam nozzle calibrations. In general the test points of the 0.58 beta nozzle run one percent higher than predicted by ASME. The larger nozzle, 0.73 beta, gave coefficients about 1.5% higher than ASME. However, a water calibration at a lower

Reynolds number seemed to check out the steam points.

The orifice calibration is shown in Figure 5. The water coefficients ran about one half percent lower than ASME. The steam points were about one percent higher than ASME.

Complete test data are given in Table 2.

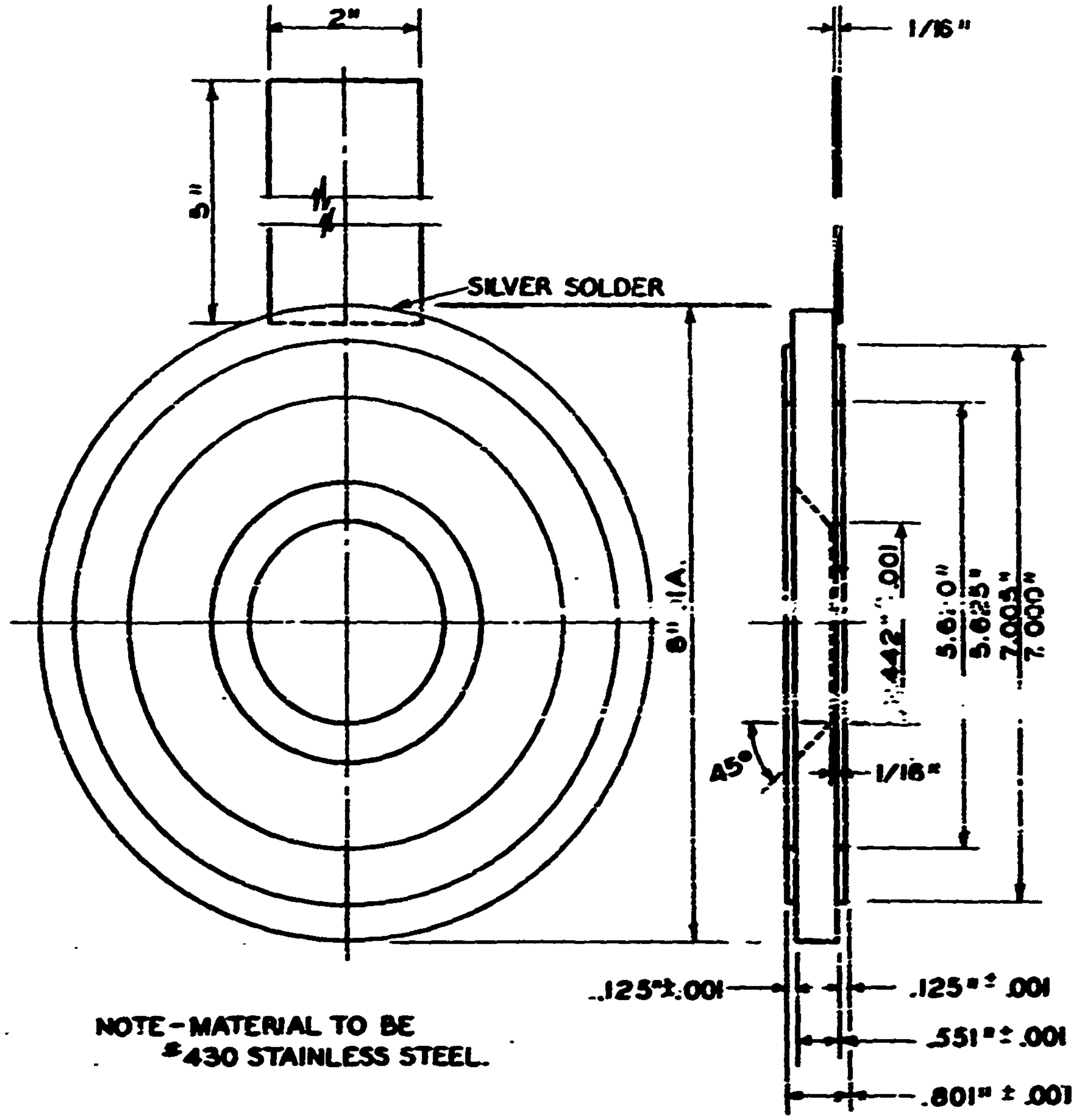
The ASME Research Committee on Fluid Meters is currently obtaining data from a number of related programs and the data contained herein must be correlated with that obtained from those other programs. Consequently, no attempt has been made to interpret the test results. This report is a presentation of data together with methods used in obtaining it.

Table 2

Test Data

| Date | Run No. | Ambient Temp. F | Time of Run Minutes | WATER DATA Man. Inches | WATER DATA Temp. F | WATER DATA Press. psia | WATER DATA Flow Lb/Hr | WATER DATA Reynolds Number $R_D X10^{-6}$ | Coefficient of Disch. C | STEAM DATA Man. Inches | STEAM DATA Temp. F | STEAM DATA Press. psia | STEAM DATA Flow Lb/Hr | STEAM DATA Reynolds Number $R_D X10^{-6}$ | Coefficient of Disch. C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2-14-61 | 1 | 79 | 60 | 9.03 | 253.3 | 2184 | 56,032 | 0.446 | 0.9956 | 30.47 | 1061.8 | 2017.7 | 55,942 | 3.07 | 0.9981 |
| | 2 | 81 | 54 | 17.19 | 244.0 | 2247 | 77,082 | 0.593 | 0.9905 | 58.55 | 1060.3 | 2010.9 | 76,992 | 4.23 | 0.9964 |
| | 3 | 80 | 120 | 26.34 | 236.7 | 2257 | 95,845 | 0.704 | 0.9936 | 93.19 | 1091.7 | 1994.3 | 95,755 | 5.11 | 1.0048 |
| | 4 | 81 | 132 | 18.08 | 234.5 | 2227 | 79,278 | 0.584 | 0.9916 | 62.61 | 1088.3 | 2009.7 | 79,188 | 4.25 | 1.0038 |
| 3-7-61 | 5 | 79 | 90 | 4.41 | 258.0 | 2173 | 62,047 | 0.514 | 0.9916 | 11.07 | 1032.8 | 2026.3 | 61,987 | 3.462 | 1.0023 |
| | 6 | 77 | 78 | 8.13 | 254.1 | 2266 | 84,471 | 0.680 | 0.9923 | 23.15 | 1062.9 | 1990.1 | 84,403 | 4.602 | 1.0024 |
| | 7 | 76 | 90 | 12.01 | 252.1 | 2279 | 103,169 | 0.815 | 0.9964 | 34.23 | 1058.0 | 1994.4 | 103,067 | 5.607 | 1.0056 |
| | 8 | 72 | 114 | 8.08 | 254.1 | 2257 | 84,244 | 0.678 | 0.9928 | 22.72 | 1049.6 | 1990.1 | 84,169 | 4.631 | 1.0031 |
| 6-22-61 | 10 | 81 | 120 | 9.30 | 260.8 | 2109 | 56,413 | 0.46[illegible] | 0.9894 | 30.74 | 1036.9 | 1998.9 | 56,373 | 3.151 | 0.9978 |
| | 11 | 83 | 138 | 19.44 | 254.6 | 2171 | 81,9[illegible] | 0.66[illegible] | 0.9924 | 67.42 | 1053.6 | 1975.7 | 81,829 | 4.512 | 0.9970 |
| | 12 | 84 | 96 | 26.96 | 245.2 | 2251 | 96,585 | 0.74[illegible] | 0.9913 | 97.54 | 1066.3 | 1959.2 | 96,505 | 5.323 | 0.9918 |
| | 13 | 82 | 120 | 17.70 | 243.7 | 2307 | 78,5[illegible] | 0.59[illegible] | 0.9949 | 62.88 | 1063.0 | 1981.4 | 78,489 | 4.330 | 0.9917 |
| 7-20-61 | 14 | 90 | [illegible]6 | 11.18 | 267.5 | 2160 | 41,2[illegible] | 0.35[illegible] | 0.6091* | 25.72 | 1003.6 | 2014.0 | 41,123 | 2.380 | 0.6628* |
| | 15 | 91 | 120 | 23.85 | 257.1 | 2139 | 60,5[illegible] | 0.49[illegible] | 0.6119* | 57.40 | 1034.7 | 2001.3 | 60,500 | 3.418 | 0.6661* |
| | 16 | 92 | 102 | 39.24 | 250.6 | 2172 | 77,9[illegible] | 0.61[illegible] | 0.6127* | 98.69 | 1064.0 | 1983.7 | 77,840 | 4.304 | 0.6677* |
| | 17 | 89 | 96 | [illegible]3.36 | 256.0 | 2190 | 60,390 | 0.47 | 0.6156* | 57.18 | 1023.4 | 2000.6 | 60,310 | 3.360 | 0.6692* |
| 11-22-61 | 19 | 72 | 150 | 4.900 | 259.8 | 2210 | 65,246 | 0.54[illegible] | 0.9886 | 12.74 | 1039.7 | 1997.5 | 65,141 | 3.502 | 1.0317** |
| | 20 | 69 | 120 | 8.72[illegible] | 2[illegible]2.6 | 2179 | 87,643 | 0.69 | 0.9935 | 23.75 | 1066.0 | 1973.4 | 87,553 | 4.619 | 1.0361** |
| | 21 | 70 | 108 | 12.98 | 247.7 | [illegible] | 107,121 | 0.83[illegible] | 0.9940 | 36.41 | 1065.3 | 1943.9 | 107,038 | 5.665 | 1.0339** |
| 12-19-61 | 22 | 73 | 174 | 48.35 | 72.3 | 610 | 210,71[illegible] | 0.3[illegible] | 0.9917 ←— Nozzle 129858 | | | Water Calibration Only | | | |
| | 22 | 73 | 174 | 5.663 | 72.3 | 467 | 210,71[illegible] | 0.3[illegible] | 1.0006 ←— Nozzle 133184 | | | | | | |
| 1-29-62 | 23 | 70 | 108 | 5.115 | 258.8 | 2125 | 67,[illegible] | 0.5[illegible] | 0.9966 | 13.55 | 985.0 | 1997.7 | 67,056 | 3.847 | 1.0035 |
| | 24 | 73 | 120 | 8.304 | 259.1 | 2264 | 85,[illegible] | 0.70[illegible] | 0.9891 | 22.74 | 1016.0 | 1977.8 | 84,833 | 4.783 | 1.0022 |
| | 25 | 73 | 120 | 12.93 | 259.6 | 2279 | 106,[illegible] | 0.87 | 0.9969 | 36.28 | 1017.0 | 1948.5 | 106,710 | [illegible].977 | 1.0099 |
| | 26 | 74 | 90 | 8.806 | 262.2 | 2284 | 87,[illegible] | 0.7[illegible] | 0.9873 | 23.39 | 1009.0 | 1975.1 | 87,145 | 4.867 | 1.0130 |

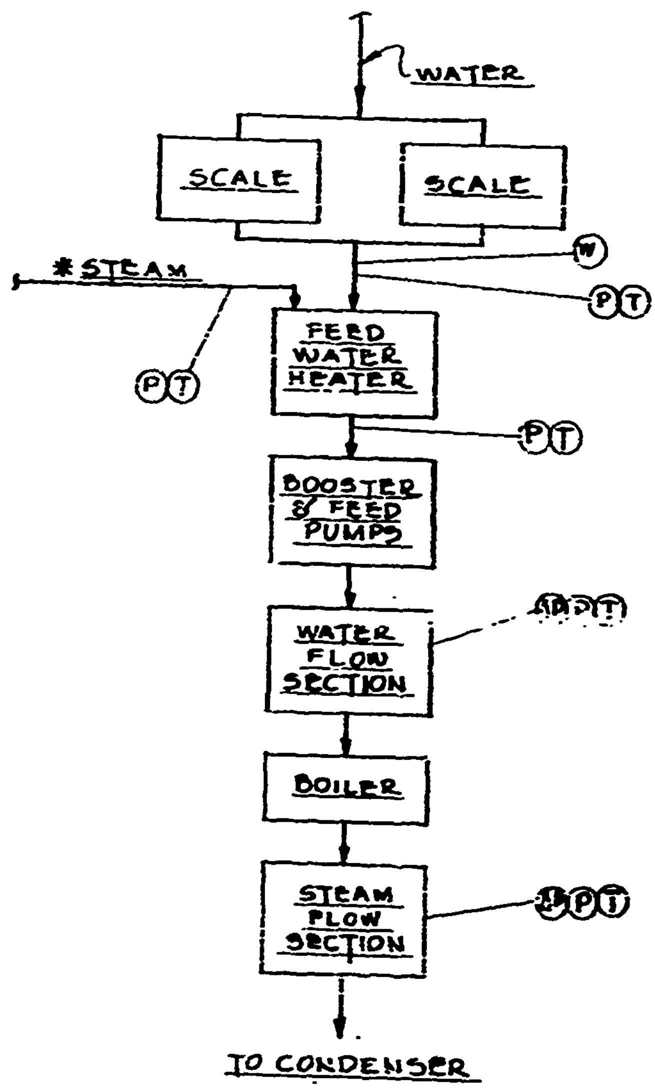
* Flow Coefficient, K
** Data Not Plotted Because Of Questionable Condition Of [illegible]ler




NBTL ORIFICE CONSTRUCTION

FIGURE 1

## FLOW DIAGRAM

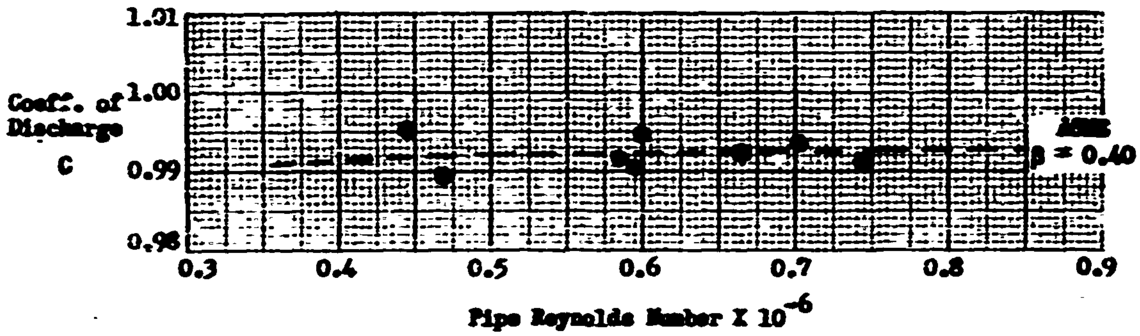



## LEGEND

ΔP - MANOMETER DIFFERENTIAL - Hg UNDER $H_2O$.
P - PRESSURE - PSIA.
T. - TEMPERATURE - F.
W - POUNDS /HR
* - STEAM RATE DETERMINED BY HEAT BALANCE ACROSS HEATER.

FIGURE 2

Nozzle No. 129857, d = 1.3734", β = 0.3887




Nozzle No. 129858, d = 1.7190", β = 0.4865

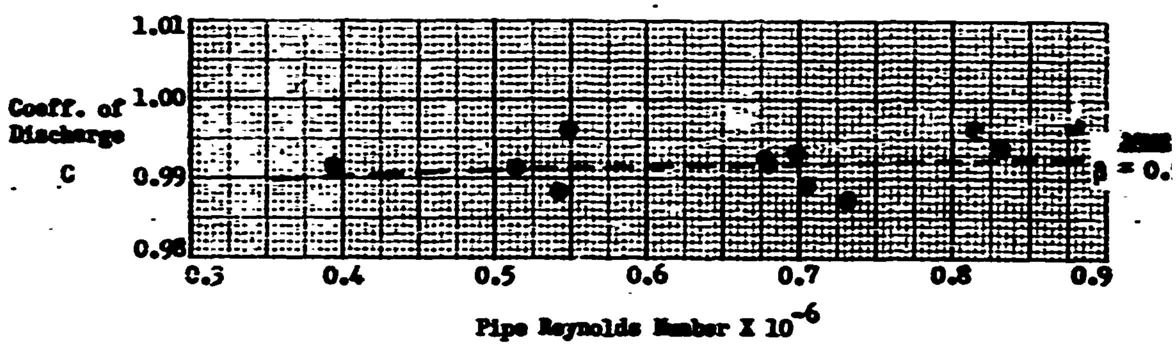
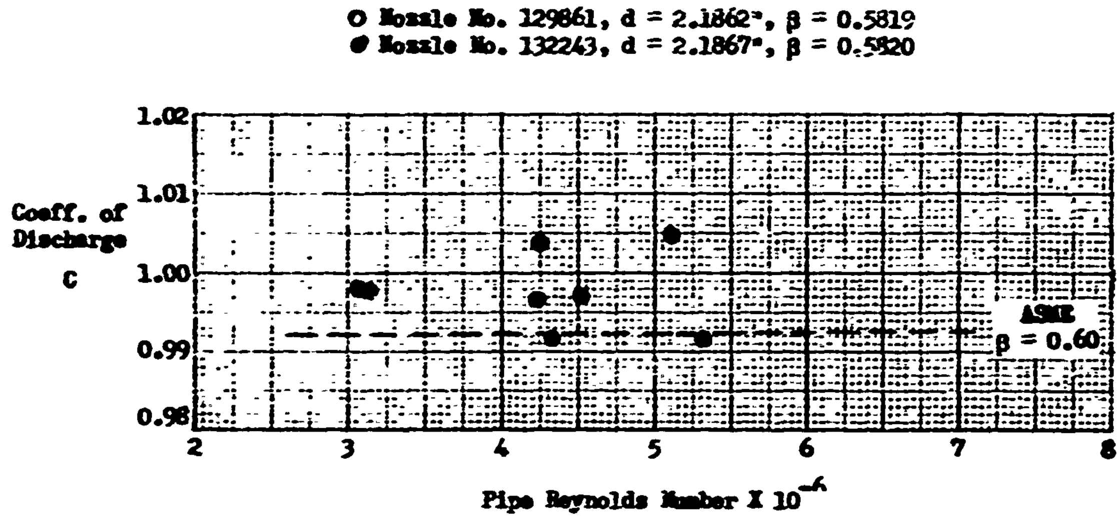



Figure 3 - Water Nozzle Calibration



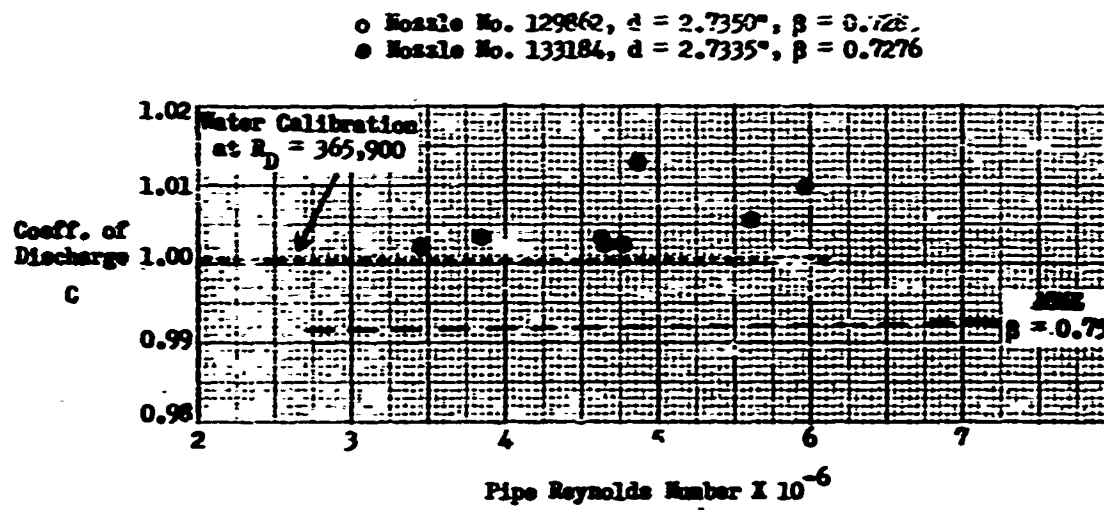
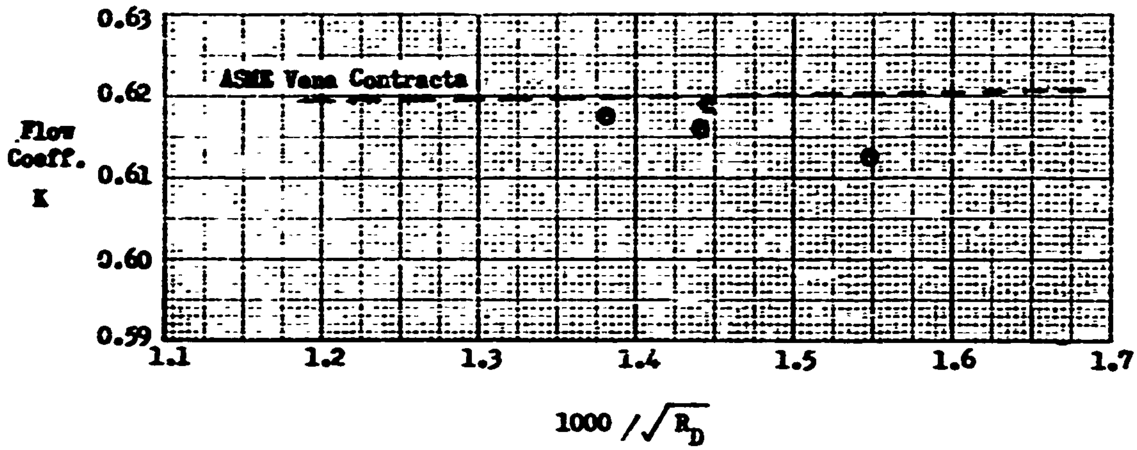




Figure 4 - Steam Nozzle Calibration

Orifice No. 129859, d = 1.4380", β = 0.4070

Water




Orifice N.B.T.L., d = 2.4425", β = 0.6501

Steam

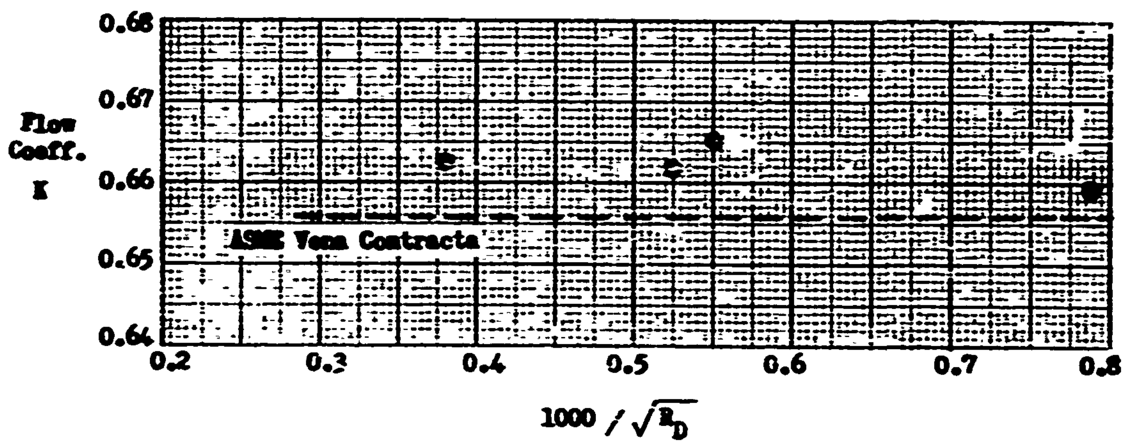



Figure 5 - Orifice Calibration

| | |
|---|---|
| Naval Boiler and Turbine Laboratory<br>Project No. I-295<br>FLOW METER CALIBRATIONS FOR THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS RESEARCH COMMITTEE ON FLUID METERS, RESEARCH AND DEVELOPMENT REPORT, by<br>C. Gregory<br>31 October 1962 7 pgs. 4 figures<br>UNCLASSIFIED<br><br>Six nozzles and two orifices were calibrated in pairs, one of a pair with water (240 F, 2200 psia) at the inlet and the other with<br>(over) | 1. High Pressure & Temperature Flow Measurement<br>I. C. Gregory<br>II. ASME<br><br>UNCLASSIFIED |
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| | |
|---|---|
| Naval Boiler and Turbine Laboratory<br>Project No. I-295<br>FLOW METER CALIBRATIONS FOR THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS RESEARCH COMMITTEE ON FLUID METERS, RESEARCH AND DEVELOPMENT REPORT, by<br>C. Gregory<br>31 October 1962 7 pgs. 4 figures<br>UNCLASSIFIED<br><br>Six nozzles and two orifices were calibrated in pairs, one of a pair with water (240 F, 2200 psia) at the inlet and the other with<br>(over) | 1. High Pressure & Temperature Flow Measurement<br>I. C. Gregory<br>II. ASME<br><br>UNCLASSIFIED |
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Type 430 stainless steel proved a better material of construction for the steam conditions than 2-1/4% chrome-molybdenum steel. The latter material showed considerable rusting and pitting after less than 10 hours of operation.

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